

METHOD FOR MAINTAINING CANDIDATE HANDOFF LIST FOR AIRBORNE CELLULAR SYSTEM

Field of the Invention

The present invention relates generally to a wireless communications system including
5 an airborne repeater, and particularly to dynamic maintenance of a terrestrial cell site
handoff list for an airborne cellular system.

Background of the Invention

The increasing need for wireless networks and communication capabilities in outlying
and geographically diverse locations has created greater demand for wireless systems.
10 Many of the new carriers providing the infrastructure for such systems have focused their
resources on building as many terrestrial cell stations as possible. As a result, the carriers
expand their respective areas of coverage and consequently generate more revenue.

However, the buildout rate for the terrestrial base stations is typically slow and
expensive, especially in mountainous areas and sparsely populated areas having few roads
15 and minimal infrastructure buildout. In addition, in some the above-mentioned sparsely
populated areas, a carrier's return on investment may not provide the incentive necessary for
the carrier to build the necessary cell stations, thereby leaving these areas with either limited
service or no wireless service at all. Further, many areas having a sufficient number of
wireless communications base stations to handle calls during both off-peak and peak times
20 cannot adequately handle temporarily large volumes of calls during sporting events or other
special events that attract large crowds for just a few days.

In response to the above, airborne wireless systems have been proposed in which a
wireless repeater mounted in an airplane, flying a predetermined flight pattern over a
geographic area requiring wireless coverage, links calls from wireless phones within the
25 covered geographic area to a terrestrial base station and other terrestrial infrastructure
components. Because the airplane is capable of traversing geographic limitations and takes
the place of the cell stations, such a system overcomes the above-mentioned problems.

Despite its many advantages, an airborne cellular system presents design and
implementation considerations not present in the design and implementation of conventional
30 terrestrial cellular systems. One primary consideration relates to maintaining a list of cell
station call handoff candidates. Conventional cellular standards and protocols such as
TIA/EIA 136, GSM and CDMA IS-95 provide for such handoff candidates. In terrestrial

cellular systems, the handoff candidates are controlled in the system switch and are communicated to the handsets for power monitoring. The switch then makes handoff decisions based on power measurement reports from the handsets. The number of handoff candidates supported by the protocol is limited and typically does not vary with time. For
5 example, the number of candidates is limited to 24 in the cellular TIA/EIA 136 protocol.

In an airborne cellular system, as the airplane circles in its flight pattern, communications beams radiated from the airplane antenna move relative to the ground thereby causing the system to perform call handoffs as beams rotate into and out of predetermined system areas of coverage. As an airborne cellular system covers a typically
10 broad geographic area, each system beam potentially interacts with a large number of terrestrial cell sites. Therefore, it is likely that the total number of terrestrial cell sites that any given beam interacts with will exceed a number of handoff candidates supported by the given cellular protocol.

In addition, an airborne cellular system provides geographic coverage at the expense
15 of large call capacity. Therefore, if an airborne cellular system were deployed in a predominantly low-density region that has pockets of high density, it would be desirable for a service provider to build terrestrial system cell stations in the high-density pockets and provide service to the remaining low-density areas with an airborne cellular system or systems. However, communications beams from the airborne cellular system would likely
20 overlap with those of the terrestrial system cell stations. As the terrestrial system cell stations would typically have higher power than the communications beams of the airborne cellular system, system users would tend to gravitate to the terrestrial system cell stations in overlapping areas.

Users in areas not covered by terrestrial cell stations initially communicate through the
25 airborne cellular system and can potentially switch over to the terrestrial system, as it may be desirable to hand off user calls from the airborne cellular system to the terrestrial system cell stations to reduce capacity on the airborne cellular system. As there are often hundreds of hundreds of terrestrial system cell stations, the airborne cellular system must generate a corresponding handoff candidate list that includes hundreds of cell station handoff
30 candidates. Unfortunately, such a handoff candidate list is currently beyond the capability of standard cellular protocols and clearly a need exists for solutions to the foregoing problems.

Brief Description of the Drawings

Advantages of the present invention will be readily apparent from the following detailed description of preferred embodiments thereof when taken together with the accompanying drawings in which:

5 FIG. 1 is a system diagram of an airborne cellular communications according to the present invention;

 FIG. 2 is a block diagram illustrating the components of the airborne cellular communications system shown in FIG. 1 in more detail;

10 FIG. 3 is a plan view of a beam pattern from an airborne repeater providing cellular coverage to a predetermined geographic area below as well as terrestrial cell stations that are handoff candidates;

 FIG. 4 is a plan view of a single beam such as one of the beams in the beam pattern in FIG. 3 showing terrestrial cell stations within the beam pattern that are handoff candidates; and

15 FIG. 5 is a flow diagram of the handoff candidate list methodology in accordance with a preferred embodiment of the present invention.

Detailed Description of a Preferred Embodiment

Referring now to the drawings in which like numerals reference like parts, FIG. 1 shows an airborne cellular communications system 10. The system 10 generally includes three primary segments: a cellular infrastructure segment 12, a radio infrastructure segment 14, and an airplane segment 16. These three segments in combination are capable of providing cellular communications coverage to a large geographical area by enabling system users, represented generally by handsets 18, to link to a public switched telephone network (PSTN) 20 via an airplane payload 22 including a repeater. The structure and
25 function of each of these three system segments will be discussed in detail.

 The cellular infrastructure segment 12 includes a mobile switching office (MSO) 24 that includes equipment, such as a telephony switch, voicemail and message service centers, and other conventional components necessary for cellular service. The MSO 24 connects to the PSTN 20 to send and receive telephone calls in a manner well known in the art. In
30 addition, the MSO 24 is connected to an operations and maintenance center (OMC) 26 from which a cellular system operator manages the cellular infrastructure segment 12. The MSO 24 is also connected to one or more base transceiver stations (BTSS) such as the BTSS

shown at 30a, 30b. The BTSs 30a, 30b transmit and receive RF signals from the system users 18 through the radio infrastructure segment 14.

More specifically, the BTS 30 transmits and receives RF signals through ground converter equipment 32. The ground converter equipment 32 converts terrestrial cellular format signals to C-band format signals and communicates with the airborne payload 22 through a feeder link 33 and a telemetry link 34, each of which will be discussed later in detail. The payload 22 establishes a radio link 36 for connecting calls over a wide geographic area of coverage, or footprint, that is capable of exceeding 350 km when the airplane maintains a flight pattern at or around 30,000 feet above the ground.

In addition to the airplane 35, the airplane segment 16 also includes an airplane operations center 37 that controls mission logistics based at least in part on information from sources such as a weather center 38, and manages all system airplanes, as the system preferably includes three airplanes to ensure continuous coverage. The airplane also receives additional routine instructions from sources such as an air traffic control center 40.

FIG. 2 shows certain components of the system 10 in more detail. Specifically, the ground converter equipment 32 includes a C-band antenna 42 for receiving/transmitting signals from/to the payload 22 (a second antenna is also provided for redundancy purposes), and a C-band converter 44 for appropriately converting the signals received from or to be transmitted to the payload 22. According to a preferred embodiment, the C-band antenna 42 and the converter 44 enable 800 MHz airborne cellular antennas 70 to communicate with the BTSs 30a, 30b via an established downlink, or feeder link, 33, and the converter 44 upconverts nominal signals from the BTSs 30a, 30b to C-band signals before the signals are transmitted to the airplane 35. Also, each BTS 30a, 30b is assigned a different band in the C-band spectrum so that signals from the different BTSs 30a, 30b can be separated and routed to the correct antenna, such as the antenna 56, at the payload 22. In addition, the ground control equipment 32 includes telemetry components such as a telemetry antenna 46, a telemetry modem 48 and a telemetry processor 50 to receive and process airplane data transmitted from an airplane telemetry antenna 52 over a telemetry link 34, while a control terminal 54 controls transmission of the processed telemetry data to the OMC 26 and the airplane operations center 37.

In the airplane segment 16, the airplane telemetry antenna 52 mentioned above transmits airplane avionics data generated by airplane avionics equipment, represented generally at 58, including airplane location, direction and flight pattern data as well as other data such as airplane pitch, roll and yaw data. The data from the airplane avionics

equipment 58 is input into and processed by a payload processor 60 before being output to the telemetry antenna 52 through a telemetry modem 62. The payload processor 60 is also responsible for processing signals transmitted to and received from the ground converter equipment 32 through the feeder link 33 established between the C-band antennas 42, 56 and for processing signals transmitted to and received from the system users 18 through a downlink, or user link, 69 established between the users 18 and a payload downlink antenna such as an 800 MHz antenna 70, with the signals received by and transmitted from the payload being appropriately upconverted or downconverted by an 800 MHz converter 72. The payload 22, in addition to including the above-mentioned equipment, also includes GPS equipment 74 that can also be input into the processor 60 and transmitted to the ground converter equipment 32 or to the airplane operations center 37 for flight control and/or monitoring purposes. The components shown in the airplane and in the payload together form the airplane repeater that enables cellular coverage to be provided to a large geographic area that may otherwise not support terrestrial cellular coverage due to an insufficient number of cell stations or the like.

As should be appreciated from the system configuration shown in FIGs. 1 and 2, both the airborne cellular system 10 and conventional terrestrial cellular systems appear identical to the PSTN 20 and the system users 18. In other words, there are no discernable service-related differences between calls linked to the PSTN 20 through the cellular infrastructure, radio infrastructure and airplane segments 12-16 and calls handled through a conventional terrestrial system infrastructure, in part due to the fact that the cellular infrastructure segment 12 includes a standard telephony switch in the MSO 24 and BTSs 30a, 30b that are identical or nearly identical to those included in a conventional terrestrial system infrastructure.

Still referring to FIGs. 1 and 2, operation of the components of the airborne cellular system 10 during completion of a call made by one of the system users 18 will now be described. The airplane 35, when on-station preferably flies in a circular or near circular flight pattern (although the flight pattern may vary according to specific weather and coverage conditions) to provide coverage to a predetermined geographic area during a mission. While it is on-station, the airplane maintains contact with the ground converter equipment 32 to provide both the feeder link 33 and the user link 36 for the cellular infrastructure segment 12 through the radio infrastructure equipment segment 14. The airplane 35 also transmits a predetermined number of communications beams, such as, for example, 13 beams, over the coverage area, with each beam being assigned to a sector of

one of the BTSs 30a, 30b and having its own set of control and traffic channels to carry signaling and voice data between the system users 18 and the cellular infrastructure segment 12. As the airplane 35 moves in its flight pattern, the beams radiated from the airplane rotate. Therefore, the system users 18 will "see" a different beam every 45 seconds or so and the cellular infrastructure segment 12 performs a sector to sector handoff of the call to keep the call from being dropped.

When initiating a call, a system user, such as one of the users 18, utilizes the control channels in the beam to signal the MSO 24 to request a call setup. The request is sent from a handset of the user 18 to the airplane payload 22, and then is relayed to the ground converter equipment 32. The ground converter equipment 32 relays the request to the corresponding BTS, such as the BTS 30a. The BTS 30a then transmits the request to the MSO 24, which sets up the call with the PSTN 20. The payload 22 therefore simply extends the physical layer of the BTS 30 to the users 18 to allow a much wider area of coverage than would typically be provided by a conventional terrestrial system, and with less associated infrastructure buildout cost. The airborne system 10 is also preferable for providing temporary cellular coverage for special events areas, where coverage is only needed for several days, thereby eliminating the need and cost associated with erecting cell stations and then tearing the cell stations down after the special events end.

Once the call setup is completed, voice communication with the PSTN 20 through the traffic channels in the beam is initiated, and voice information is then relayed in the same manner as the signaling information. When the call ends, a signal is sent to the MSO 24 to tear down the call, the handset of the user 18 releases the traffic channel used for voice communications, and the channel is returned to an idle state.

FIG. 3 shows an exemplary footprint 80 generated by the airplane segment 16 of the airborne cellular system 10. The footprint is formed from beams 82-94 radiated from the antenna 70, which is preferably a phased-array smart antenna of the type disclosed in U.S. patent application titled SMART ANTENNA FOR AIRBORNE CELLULAR SYSTEM by _____ (Motorola docket IRI05304), filed on June 26, 2000 the contents of which are incorporated herein by reference. Except for the center beam, each of the beams rotates as the airplane 35 executes its flight pattern. Therefore, terrestrial cell stations, such as the cell stations A1-A4 and B1-B2, correspondingly rotate in and out of coverage of the beam footprints of each of the respective beams. In FIG. 3, the flight pattern of the airplane is shown as rotating in a counterclockwise direction as indicated by the flight pattern direction arrow FP. The beams 82-94 correspondingly rotate in the same direction relative

to the geographic area of coverage, but remained fixed relative to the airplane 35 as the airplane executes its flight pattern.

Each of the beams, such as the beam 93, therefore sweeps out a large area and potentially overlaps with many terrestrial sites. A static handoff candidate list would require having not only those terrestrial sites currently under the beam, such as sites A1 and A3, and those sites that will soon be under the beam, such as sites A2 and A4, but also sites B1 and B2. Therefore, a system handoff candidate limit, which is typically 24 candidates, may be far exceeded.

To reduce the number of candidates, the beam handoff candidate maintenance technique in accordance with the present invention initially generates the handoff list as a function of beam location. Therefore, the beam 93 would only include sites A1-A4 as handoff candidates and would not include sites B1-B2, while the beam 87 would include sites B1 and B2 as candidates and not sites A1-A4. As the airplane executes its flight pattern, the candidate list for each beam will change so that when the beam 93 covers the terrestrial sites B1-B2, candidates B1-B2 would replace candidates A1-A4.

The beam handoff candidate maintenance technique of the present invention periodically determines a handoff candidate list for each beam based on a dynamically updated handoff list database maintained in the OMC 26. The database contains stored terrestrial cell site locations used, along with airplane position and airplane heading data input to the OMC 26 through the airplane telemetry link 34, to calculate the cell site candidate handoff list. The OMC 26 can generate a handoff candidate list including only a predetermined number of highest probability/priority candidates and can update/modify the list as a function of time. For example, in an airborne cellular system in which TIA/EIA 136 protocol is utilized, only the top 24 handoff candidates based on handoff priority would be included in a handoff list for each beam.

For example, referring still to FIG. 3, a user being serviced by the beam 93 would have beams 92, 94, at a minimum, as time sensitive handoff candidates. As the airplane 35 executes its flight pattern, the payload 22 will continuously monitor beams 92, 94 as handoff candidates. The payload 22 will also have terrestrial cells A1-A4 as time insensitive candidates. These time insensitive candidates are periodically evaluated to facilitate handoffs between the airplane 35 and the terrestrial system to alleviate capacity constraints on the system 10. These handoff candidates are time insensitive, as a delay in the handoffs between the airplane 35 and the terrestrial system will impact only the potential capacity of the beam 93 and will not impact call performance. As a result, the handoff

candidate list at any given time will include several time sensitive handoff candidates that continuously occupy slots within the handoff candidate list, and time insensitive handoff candidates that only periodically occupy slots within the handoff candidate list.

Referring now to FIG. 4, prioritization of handoff candidates to determine how frequently the candidates are included in the cyclically generated handoff candidate list associated with a communications beam in accordance with the present invention will now be discussed. Such prioritization is necessary due to the potentially large number of time insensitive handoff candidates and the small number of handoff candidate list slots, and is based on the probability of a given terrestrial cell being the best handoff cell for a user. In a preferred embodiment, the prioritization is based on the subscriber density associated with a cell. High-density cells will most likely receive the most handoffs, and therefore are ranked as higher priority candidates than low-density cells. High priority candidates would therefore be cycled into the time insensitive handoff candidate list slots more frequently than the low priority candidates.

As shown in FIG. 4, a subscriber, for example, at location C1 in a cell 96 formed by a beam 95 would have a cell 97 formed by a beam 98 as a time sensitive handoff candidate that would continuously occupy a handoff candidate list slot. Terrestrial cells C2-C5, which are located at the outskirts of coverage for an urban area with high user density, would also be high priority candidates. Therefore, C1-C6 would be frequently cycled through the handoff candidate list. Cell C6, which provides coverage for a small rural town with a low user density, and cell C7, which is in the middle of the defined urban coverage area, would be defined as low priority candidates and therefore would be cycled through less frequently on the handoff candidate list. More specifically, cell C7 would be considered a low priority candidate, as a user call would be linked directly through the cell C7 to the corresponding terrestrial system rather than through the system 10 if the user were in close proximity to the cell C7.

The handoff candidate list database which is preferably maintained in the OMC 26 is therefore dynamically updated by the above-described preferred embodiment in accordance with the present invention based on airplane location, the distinction between time sensitive and time insensitive handoff candidates, and the prioritization of time insensitive handoff candidates based on subscriber density. Alternative embodiments could prioritize time insensitive candidates based on factors other than subscriber density in accordance with system-specific parameters. Also, a relative ranking of all handoff candidates can be established based on the relative densities associated with each of the handoff candidate

cells and based on the relative need for a user to be handed off from one beam to another in the system 10 to further prioritize the high and low priority handoff candidates.

If an excessive number of candidates exist after the high priority list is generated, the technique of the present invention can further reduce the number of candidates by periodically cycling through those handoff cell candidates within the footprint of the beam that are not time-sensitive. In other words, ground-based cell sites, which are not time-sensitive, may be divided into multiple groups within the beam to provide the technique in accordance with the present invention with a higher-ranking resolution. The handoff list maintenance technique may then cycle through only these groups of non-time sensitive cells more regularly to provide a more precise update of the handoff list without affecting hand offs of time-sensitive cells, such as the cell C1 in FIG. 3. Even though an associated handoff delay of, for example, 15 seconds or so would be associated with cycling through the multiple groups of non-time-sensitive cells, such a delay is acceptable.

FIG. 5 is a flow diagram illustrating the methodology of the candidate handoff list maintenance technique of the present invention generally at 100. The process at 102 initially determines airplane position and heading via GPS data provided from the airplane 35 through the telemetry link 34, as well as beam position data for each communications beam at 104. At 106, handoff candidate probability calculations are performed as discussed above and based in part on terrestrial cell site location data stored in the cellular system handoff coordination database at 108. After the above calculations are made, at 110 handoff candidates are ranked and high priority candidates are identified. At 112, it is determined whether an excessive number of candidates exist within a particular beam. If an excessive number of candidates do exist, the above-described determination of non-time sensitive candidates may be performed at 114, and the time insensitive candidates are subsequently periodically cycled through at 116. At 118, the handoff candidate list is then updated after the time insensitive handoff candidates are cycled through to generate the handoff candidate list at 120.

If at 112 an excessive number of candidates is determined not to exist, the handoff candidate list is updated at 118 to produce the handoff candidate list at 120 without determining and cycling through time insensitive candidates at 114 and 116, respectively. Also, as indicated by the dashed line at 122, the ranking operation at 110 and the excessive candidate determination at 112 may be skipped, and the technique may proceed directly from performing a handoff candidate probability calculation at 106 to performing periodic cycling through time insensitive candidates at 116.

In addition to facilitating handoffs from an airborne cellular system to terrestrial system cell sites, it is also contemplated that the candidate handoff list maintenance technique of the present invention may be designed to facilitate handoffs in a manner opposite to that described above, or, in other words, to enable handoffs from a terrestrial system to an adjacent airborne communications system. In such a case, terrestrial cells bordering on or overlapping the airborne system coverage area would also require a time-varying handoff candidate list as well. The list would function in a manner similar to the list described above, except that the communications beams, rather than the terrestrial cells, would be the handoff candidates. As there would be usually only one or two beams over a terrestrial cell at one time, however, a cyclical approach would not be required.

As should now be appreciated from the foregoing discussion, the candidate beam hand-off list maintenance technique of the present invention facilitates terrestrial system interoperability with an airborne cellular system by enabling reliable handoffs to be made between wide area coverage airborne cellular systems and terrestrial systems for overlay applications. The present invention also facilitates reliable handoffs between adjacent airborne cellular systems, and is capable of distinguishing between time-sensitive and non-time sensitive handoff candidates based on such factors as terrestrial cell user densities.

While the above description is of the preferred embodiment of the present invention, it should be appreciated that the invention may be modified, altered, or varied without deviating from the scope and fair meaning of the following claims.